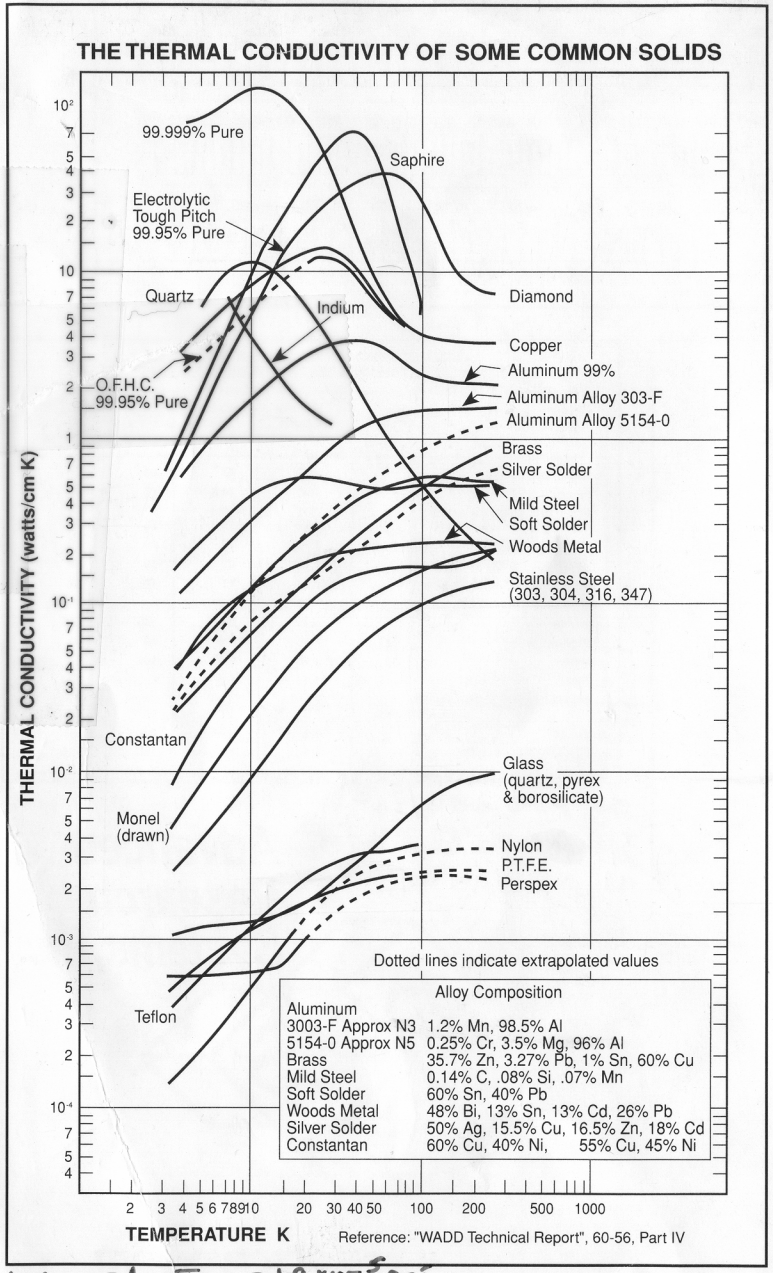

Reference: "WADD Technical Report", 60-56, Part IV

1 micron = 1 m Torr = 1.9 x 10⁻⁵ psi

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1 mm Hg = 1000 micron = 1 torr

1 mbar = 0.750 torr

1 torr = 1.934 x 10⁻² psi = 1 mm Hg

Advanced Research Systems, Inc.

LN2 density 1.78 lb/L, 6.74 lb/gal LN2 latent heat 161 kJ/L

THERMAL CONDUCTIVITY OF COPPER WIRE

Heat conducted along 10cm of copper wire with one end at 4°K and the other at temperature T	Wire Gauge (S.W.G.)		40	38	36	34	32	30	28	26	24	22	20	18	16
	Diameter mm		0.122	0.152	0.193	0.234	0.274	0.315	0.376	0.457	0.559	0.711	0.914	1.219	1.626
	Cross sectional area (Cm^2 x 10^{-3})		0.117	0.182	0.293	0.429	0.591	0.779	1.11	1.642	2.452	3.973	6.567	11.68	20.76
	Heat Conducted	T = 300°K	17.8	27.8	44.6	65.2	89.8	119	169	250	372	603	998	1774	3155
	Milliwatts	T = 77°K	6.85	10.6	17.2	25.1	34.6	45.7	65	96.3	143.7	233	385	684	1215

LAr density 3.07 lb/L, 11.63 lb/gal LAr latent heat 225.7 kJ/L 73.42 kJ/lb

SELECTED PROPERTIES OF CRYOGENIC LIQUIDS AT THE NORMAL BOILING POINT

Saturated-Liquid Property at 1 atm		Liquid Helium 3	Liquid Helium 4	Liquid Hydrogen	Liquid Neon	Liquid Nitrogen	Liquid Air	Liquid Flourine	Liquid Argon	Liquid Oxygen	Liquid Methane
Normal boiling point	K	3.19	4.214	20.27	27.09	77.36	78.8	85.24	87.28	90.18	111.7
	°R	5.74	7.58	36.5	48.8	139.3	142	153.4	157.1	162.3	201.1
Critical temperature	K	3.32	5.20	33.2	44.4	126.1	133	144.0	150.7	154.6	190.7
	°R	5.98	9.36	59.7	79.9	227.0	240	259.2	271.2	278.3	343.3
Critical pressure	MPa	0.117	0.229	1.315	2.65	3.39	3.92	5.57	4.89	5.08	4.64
	atm	1.15	2.26	12.98	26.2	33.5	38.7	55.0	48.3	50.1	45.8
Triple-point temperature	K	...	[a]	13.9	24.54	63.2	...	53.5	83.8	54.4	88.7
	°R	...	[a]	25.1	44.26	113.7	...	96.4	150.8	98.0	159.7
Triple-point pressure	kPa	...	[b]	7.20	43.3	12.85	...	0.221	68.8	0.152	10.0
	atm	...	[b]	0.0711	0.427	0.127	...	0.00218	0.679	0.0015	0.099
Density	kg/m^3	58.9	124.8	70.79	1206	807.3	874	1507	1394	1141	424.1
	lb_m/ft^3	3.68	7.79	4.42	75.3	50.4	54.6	94.1	87.0	71.2	26.5
Latent heat	kJ/kg	8.49	20.90	443	85.9	199.3	205	166.3	161.9	213	511.5
	Btu/lb_m	3.65	8.98	190.5	36.9	85.7	88.1	71.5	69.6	91.6	219.9
Specific heat	kJ/kg-K	4.61	4.48	9.68	1.83	2.05	1.96	1.54	1.136	1.695	3.461
	Btu/lb_m-°R	1.10	1.07	2.31	0.437	0.490	0.468	0.367	0.271	0.405	0.827
Viscosity	μPa-s	1.62	3.56	13.2	130	158	168	244	252	190	118
	lb_m/ft-hr	0.0039	0.0086	0.0319	0.314	0.382	0.407	0.542	0.610	0.460	0.285
Thermal conductivity	mW/m-K	17.1	27.2	118.5	113	139.6	141	148	123.2	151.4	193.1
	Btu/hr-ft-°F	0.0099	0.0157	0.0685	0.653	0.0807	0.0815	0.0855	0.0712	0.0875	0.1116
Dielectric constant	ϵ_r	...	1.049	1.226	1.188	1.434	1.445	1.43	1.52	1.484	1.676
Speed of sound	m/s	115	181	1189	...	856	866	...	847	902	1411
	ft/sec	376	593	3900	...	2810	2840	...	2780	2960	4630

[a] Lambda-point temperature = 2.171 K = 3.91°R.
[b] Lambda-point temperature = 5.073 kPa = 0.050 atm.

Reference: Cryogenic Systems, Randall F. Barron, P 44, 1985 Oxford University Press

SELECTED MINIMUM TOTAL EMISSIVITIES*

Surface	Surface Temp. K 4	20	77	300
Copper	0.0050		0.008	0.018
Gold			0.01	0.02
Silver	0.0044		0.008	0.02
Aluminum	0.011		0.018	0.03
Magnesium				0.07
Chromium			0.08	0.08
Nickel			0.022	0.04
Rhodium			0.078	
Lead	0.012		0.036	0.05
Tin	0.012		0.013	0.05
Zinc			0.026	0.05
Brass	0.018		0.029	0.035
Stainless steel, 18-8			0.048	0.08
50 Pb 50 Sn solder			0.032	
Glass, paints, carbon				>0.9
Silver plate on copper		0.013	0.017	
Nickel plate on copper		0.027	0.033	

*These are actually absorptivities for radiation from a source at 300 K.

Normal and hemispherical values are included indiscriminately.

Reference: Applied Cryogenic Engineering, Edited by R.W. Vance and W.M. Duke, P 154, 1962 John Wiley and Sons Inc.

80K OK

Room to LN2 to LHe

Cu	.0031	.0034
S.S.	.00291	.0030
Al	.00394	.0048
Teflon	.0139	.016

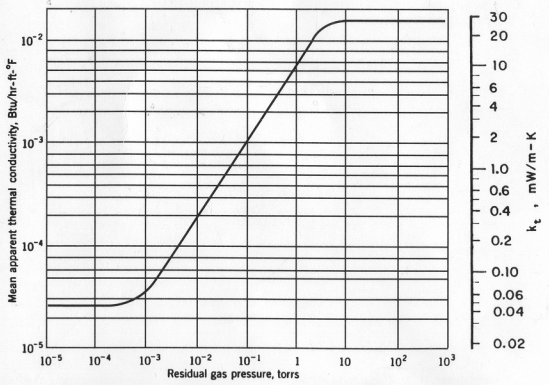
Shrinkage per foot from 300K

1 lb/ft-hr = 0.413 centipoise

LN2 static head = 0.35 psi/ft

LAr static head = 0.60 psi/ft

Multilayer Insulation(MLI)



AMOUNT OF CRYOGENIC FLUID REQUIRED TO COOL METALS

FLUID		HE^4				H_2				N_2	
Initial Temp. of Metal		300 K		77 K		300 K		77 K		300 K	
		σ	liters per lb.	σ	liters per lb.	σ	liters per lb.	σ	liters per lb.	σ	liters per lbs.
Using the latent heat of vapour-ization only	Aluminium	8.3	30.2	0.4	1.45	0.38	2.42	0.018	0.12	0.81	0.46
	Stainless Steel	4.2	15.1	0.18	0.65	0.2	1.28	0.0085	0.05	0.43	0.24
	Copper	3.9	14.1	0.27	0.98	0.17	1.08	0.012	0.08	0.37	0.21
Using the enthalpy of the gas.	Aluminium	0.2	0.73	0.028	0.1	0.075	0.48	0.0097	0.06	0.51	0.29
	Stainless Steel	0.1	0.36	0.013	0.05	0.037	0.24	0.0045	0.03	0.27	0.15
	Copper	0.1	0.36	0.02	0.07	0.037	0.24	0.0065	0.04	0.23	0.13

The data given above is the specific liquid requirement σ, (the weight of fluid required to cool the same weight of metal to the fluid boiling point). The volume of liquid (liters) required to cool 1 lb. of metal to the fluid boiling point is also given.

Reference: Advances in Cryogenic Engineering, Editor; K. D. Timmerhaus, Section J-6 by R. B. Jacobs, P 529-535, 1963 Plenum Press

	density at STP lb/ft³	kg/m³	μ Cp (warm)
air	.07491	1.2 kg/m³	.018
Ar	.1034	1.784	.022
N_2	.07247	1.16	.018
O_2	.0826	1.309	.021

k (w/m-K) (warm)

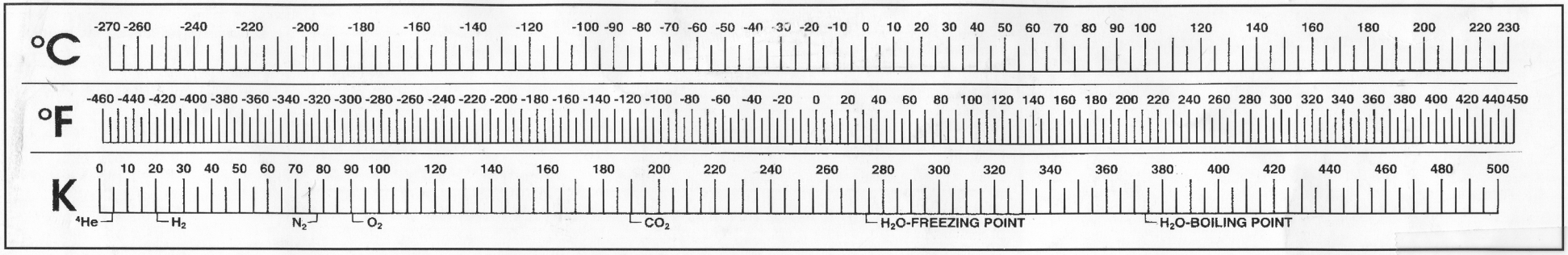
Ar 0.018 O_2 .0266

N_2 .025

Air 0.025

1 micron = 10^{-3} Torr

$\frac{\text{Torr liter}}{\text{sec}} \times 1.32 = \frac{cm^3}{sec}$ (NTP)



MEAN LINEAR THERMAL EXPANSION OF VARIOUS MATERIALS

Expansion, $\Delta L/Li \times 10^5$

Material	Molded Polyester Rod Reinforced with Glass Fiber	Cast Phenolic Rod	Cast Epoxy Polymer	Nylon Rod	Flourothene	Polystyrene[a]	Poiytetra-flouro-ethylene[a]	Pyrex[b]	Cu	Ni	Al	Mg	Zn	Ti	1020 Low-Carbon Steel	304 Stainless Steel	Monel	Inconel	Free-Machining Yellow Brass
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	3	14	10	10	21	27	45	-1	0	0	0	1	1	0	0	-1.1	0	0	0
40	11	38	39	37	65	82	115	-2	2	1	2	5	9	1	1	-1.5	-1.5	1	4
60	21	70	78	81	116	152	200	-1.5	10	4	10	12	28	2	4	+2.8	6	5	15
80	34	109	126	142	173	235	300	+1	25	12	24	29	57	6	10	14	15	12	34
100	49	154	181	217	235	329	410	4.5	44	23	46	55	93	14	20	30	29	24	57
120	67	205	242	301	301	432	525	8.5	67	38	72	87	133	24	32	50	45	38	85
140	88	261	310	393	372	542	650	13	92	55	104	124	176	35	47	73	64	55	115
160	110	321	385	493	444	658	785	17.5	119	74	138	164	221	47	63	97	85	74	146
180	134	385	467	600	531	778	940	22.5	148	95	175	208	267	60	81	124	107	95	180
200	159	452	556	716	618	900	1130	27.5	178	117	214	254	314	74	101	151	130	117	214
220	184	524	651	841	711	1024	1370	33	209	140	255	303	363	89	121	180	155	140	249
240	210	602	753	977	811	1152	1620	39	240	164	297	353	413	105	142	210	180	163	285
260	237	688	862	1124	921	1284	1875	44.5	272	188	341	403	465	121	164	241	207	187	322
273.2	255	749	939	1228	1001	1374	2045												
280	264	782	980	1282	1045	1422	2130	50.5	305	213	385	453	518	138	187	272	234	212	359
300	291	889	1107	1450	1187	1566	2695	57	339	239	431	503	572	155	210	304	261	238	397

[a] Specimen taken parallel to the rod extrusion direction.
[b] Calculated from data for SiO_2 and B_2O_3.

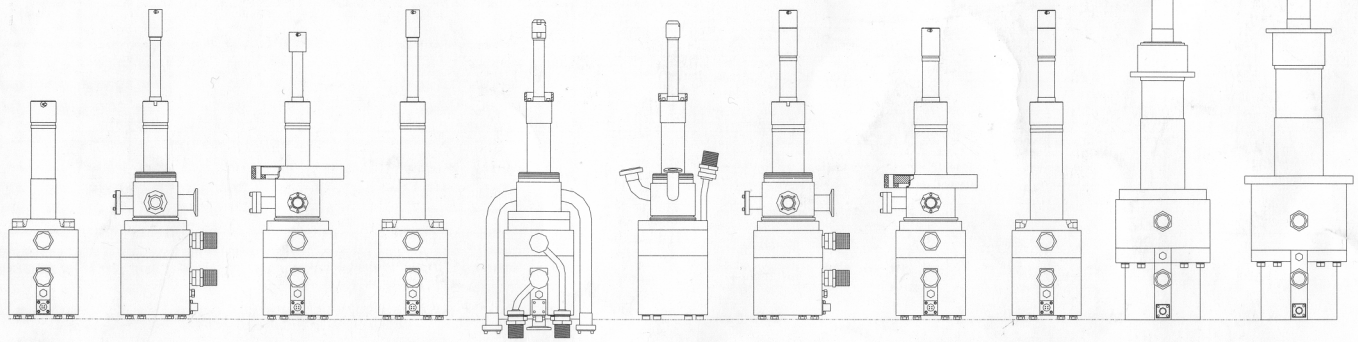
Reference: Cryogenic Engineering, Russell B. Scott, 1959 D. Von Nostrand Company Inc.

MECHANICAL PROPERTIES OF MATERIALS USED IN CRYOGENIC SYSTEMS (ROOM TEMPERATURE VALUES)

Material	Density (g/cm^3)	Young's Modules (10^6 psi)	Yield Strength (10^3 psi)	Ultimate Strength (10^3 psi)
Aluminum 1100-0	2.72	10	<5	13
Aluminum 2219-T87	2.85	10.6	57	69
Aluminum 5083 (annealed)	2.66	10.3	21	42
(half hard)	2.66	10.3	33	46
Aluminum 6061-T6	2.72	10	40	45
Beryllium S-200F	1.86	42	35	50
Copper OFHC (annealed)	8.95	17	10	32
G-10 Fibergalss epoxy	1.65	4.0	-	60
Inconel 718	8.20	29	153	185
Kapton (film)	1.43	0.5	30	45
Mylar	1.38	0.55	10	20
Nylon	1.14	0.5	-	12
Stainless steel 304 (annealed)	7.8	28	35	90
(work hardened)	7.8	28	75	110
Teflon	2.2	0.05	2.0	3.0
Titanium 6Al-4V	4.4	16.5	120	130

ss $\rho = 0.28 lb/in^3$
cu $\rho = 0.323 lb/in^3$
al $\rho = 0.10 lb/in^3$

The DISPLEX Arsenal - Targeting Your Application



DE102
15 W @ 77 K

DE104
35 W @ 77 K

DE202
< 9 K
2.5 W @ 20 K

DE202N
< 6.5 K
1 w @ 10 K

DE202S
50 mW @ 4.2 K

DE202B
UHV
200 C BAKEABLE

DE202NB

DE202SB

DE202FF
FLAT FLANGE

DE202NFF

DE202SFF

DE202G
HUBER GONIOMETERS

DE202NG

DE202SG

DE202K
NEWPORT GONIOMETERS

DE202NK

DE202SK

DE204
< 9 K
9 W @ 20 K

DE204N
< 6.5 K
3 w @ 10 K

DE204S
150 mW @ 4.2 K
3.5W @ 10 K

DE204B
UHV
200 C BAKEABLE

DE204NB

DE204SB

DE204FF
FLAT FLANGE

DE204NFF

DE204SFF

DE208S
0.5 W @
4.2 K

DE210S
0.8 W @
4.2 K

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laminar flow $\Delta P = .1225$ mL q.
d4